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Counting Crabs: Assessment of Mangrove Crab Diversity and Density Among Three Sites in Ushongo, Tanzania

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SIT Study Abroad

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SIT Wildlife Conservation and Political Ecology

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Thank you to the village of Ushongo for graciously welcoming us into your home for three weeks, especially to the mamas who fed us so well every day. I am incredibly grateful to my guide, Raim, for keeping me company and for being patient through three weeks of long walks and hours in the sun sitting silently staring at crabs, and for always bringing fruit to look forward to at the end of each data collection period! Thank you very much to my advisor, Professor Gasto Lyakurwa, for advice through the proposal and final report process, and especially for helping to narrow down the study topic to crabs. To Felicity, Oscar, and Mama Juni, and all the experts, thank you so much for all your work behind the scenes making this program continue, lots of valuable advice throughout the semester that I applied to the study design, and for coordinating and checking in with us throughout the ISP process. A big thank you and congratulations to my fellow students and friends on this program. And finally, thank you to all my loved ones for your emotional support throughout this program. I cannot wait to share it all with you.

Abstract

This study assessed the density and diversity of crabs across three mangrove forest zones in Ushongo, Tanzania. The aim was to understand variance in the composition and distribution of mangrove crabs in relation to mangrove tree composition gradients in the area. Sites were measured using a 200m line transect and 40-plot method. Data was also collected from a sand beach habitat to compare to the diversity and distribution of mangrove habitats. Diversity was analyzed using Simpson's Index of Diversity and an ANOVA test on the average number of species found per plot in each site. Density was analyzed using an ANOVA test on the number of crab individuals recorded per plot in each site. Site 1 was located on the Ushongo Rive estuary, and had the highest diversity in composition of crabs and mangrove trees. Site 2 was a homogenous stand located near Ushongo Mtoni, which had the highest abundance of crab species which indicated specialization. Site 3 was located near Ushongo Mabaoni and had the lowest diversity and highest amount of human disturbance. Overall, the study found that there was significant variance in crab composition and distribution between the three mangrove sites, which indicates correlation between crab and mangrove tree gradients. Crab studies such as this one, can be used to assess mangrove forest composition and health. Furthermore, comparison to the Sand Beach Site indicated the uniquely important biodiversity that mangrove forests support, which should continue to be monitored conserved. This information is important for use in future ISP studies and for village leaders and conservation organizations to access for future mangrove conservation plans in the area.

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Introduction

This study was carried out from November 4th, 2017 to November 24th, 2017. The aim was to examine whether a difference existed in the diversity, density, and distribution of crabs which inhabit zones of mangrove forest in the Ushongo area. The mangrove is a flowering evergreen tree which grows in sub-tropical and tropical climates along the upper-intertidal coastal zone. The intertidal zone is a harsh environment due to high salinity and tide disturbance, so organisms that inhabit this zone must be well adapted to propagate and survive in the conditions. Therefore, mangrove trees are characterized by their salt-tolerant adaptations. Such adaptations include pneumatophore roots which are a form of aerial root which indicates anaerobic conditions. Some species use salt secretion techniques such as concentrating salt into certain leaves and shedding these leaves (Richmond, 2011).

Mangroves are a unique tree because these adaptations allow them to grow and prosper in areas which span seawater and freshwater, terrestrial and marine ecosystems. Such areas include coastal lagoons, bays, and estuaries (Richmond, 2011). There are 8 species of mangrove trees in Tanzania, however only four were observed in the sites in this study: *Avicenna marina*, *Ceripos tagal*, *Rhizophora mucronata*, and *Bruguiera gymnorrhiza*. *Avicenna marina* belongs to the Acanthaceae family, has narrow, lime green leaves, yellowed bark which often peels, pencil-like pneumatophores, and is widespread in mangrove forests. It is a highly salt-tolerant tree, but is usually found in freshwater areas that are occasionally flooded by tidal waters. *Ceriops tagal* belongs to the Rhizophoraceae family. It flowers all year and is characterized by long thing fruits, small buttresses, and "knee-roots." *Rhizophora mucronata* belongs to the Rhizophoraceae family that flowers all year and can be distinguished by tall stilt roots and large dark green leaves with a pointed spine at the tip. *Bruguiera gymnorrhiza* also belongs to the Rhizophoraceae family and flowers all year. It has pyramidal buttresses, arch roots, and the fruits have red spiked caps which cover the tip of the light green long fruit. *B. gymnorrhiza* can grow in variable levels of saline and are often found mixed into *C. tagal* and *R. mucronata* zones.

Mangrove habitats are impacted by variety of environmental conditions such as climate, sedimentation rate, geologic history, tides, wave action salinity, and faunal community composition. The term mangrove refers to individual trees, while mangrove forest is used to refer to the complex and critical ecosystem made up of mangrove trees along coasts. High biomass and primary production which is higher than that of coral reefs characterize mangrove forests.

Forests are valuable because they support a diverse ecosystem due to their unique environmental niche.

Though mangrove forests in Southeast Asia are far more diverse than those in Africa, East Africa has the most diverse mangroves in all of Africa which cover 15,000km^2 (WWF). Mangrove forest zonation supports this high biodiversity diversity. Each species of mangrove has varied levels of salt-tolerance and environmental preference, which leads to zonal gradients along mangrove stands. A multitude of factors influences the distributional gradients of mangroves (Duke, et al., 1998). A study conducted in 2017 on the global diversity and distribution of terrestrial vertebrates within mangroves found a positive correlation between terrestrial vertebrate diversity and mangrove tree species richness and argued that "plant richness may directly influence richness of other taxa by determining the variety of food items or habitat structural elements that create niches for other organisms," (Rog, et. al., 2017). Similar patterns likely exist between mangrove flora and other fauna, like crabs.

Additionally, mangrove forests provide ecosystem service which are necessary for the continued health of marine habitats (Lawlor, 2013). These services range from protection from erosion, tsunamis, and flooding, water purification, nutrient cycling, climate regulation, and the provision of valuable resources such as nurseries for fish, habitat for migratory birds, and resources for people such as food, firewood, and timber. Mangrove forests are the most extensive and diverse in the Indo-West Pacific region, and can penetrate as far as 320km inland in some areas (Castro and Huber, 2005). According to some estimations, sheltered coasts, which were covered up to 75% in mangrove forests, have been depleted by half (Castro and Huber, 2005). Conservation of mangroves forests is very important to maintain the positive and necessary benefits these habitats provide. Research on mangrove forests is essential for implementing management plans which is why this is an important study project.

The coast of Tanzania is 3,641km long and covered in approximately 1,335km^2 of mangrove forest, which is the main coastal ecosystem in Tanzania (Taylor, 2003). East African mangroves are currently listed as critical/endangered (WWF). Approximately 150,000 people earn their livelihoods from mangrove resources in Tanzania as mangroves are used for poles, houses, boast construction, and in aquaculture (Taylor, 2003). Threats to mangrove stands in Tanzania include clearing mangroves for tourism, salt production, and habitat lost due to aquaculture, and increasing water pollution (Taylor, 2003). However, the mangrove area in

Tanzania has remained relatively constant due to the success of a few government-level protections. Tanzania recognized the value of mangrove forests in 1930, legally protecting all mangroves by designating them as forest reserves (Taylor, 2003). In 1994, The National Mangrove Management Plan was initiated in Tanzania with the intention of preserving mangroves while allowing sustainable use. The plan has had good results maintaining mangrove forests, particularly in the Pangani and Tanga region which includes Ushongo (Taylor, 2003).

Crabs are a key inhabitant of mangrove ecosystems, but also can be found in a range of other habitats. Crabs belong to the subphylum Crustacea and the order Decapoda, which includes lobster and shrimp, all of whom are characterized by 5 pairs of legs. The most diverse group of decapods are crabs, with over 4,500 species (Castro & Huber, 2005). Crabs are a dynamic and impactful component of mangrove ecosystems. Most mangrove crabs feed on leaf litter, though some climb trees and feed on living leaves or even feed on other crustaceans. Crabs are responsible for removing a large amount of leaf litter from the ground, exemplifying their important impact on the ecosystem. Mangrove crabs are classified as allogenic engineers because they transform organic material mechanically in such large quantities that the ecosystem would be highly altered without them (Lawlor, 2013). Crabs also may play a large role in influencing the zonation of mangrove flora because of their role as engineers aerating soil, spreading mangrove propagules, and consuming mangrove leaves (Duke, et al., 1998). *Scylla serrata*, also known as the Mangrove or Mud Crab, are heavily consumed and used as a commercial aquaculture product. Globally, there has been extensive research on crabs in mangroves because of the important role of crabs within mangroves. This research has been largely focused on more diverse mangrove areas in Southeast Asia or the Caribbean. There is a deficit in research on mangrove and the crabs which inhabit mangroves in East Africa, and Tanzania more specifically (Richmond, 2011).

Three zones of mangrove forest were examined in addition to one site in the sand beach habitat which served as a habitat comparison mechanism to shed light on the importance of mangrove forest habitats. This importance helps to explain why continued conservation of mangrove forests along the coast of Tanzania is critical. Site 1 was located at the mouth of the Ushongo River, approximately 3-4km from Ushongo Mtoni. Site 2, was located along the river near Ushongo Mtoni. Site 3 was located near Ushongo Mabaoni.

The hypothesis was that there would be significant difference in the diversity, density, and distribution of mangrove crabs among the three zones of mangrove forest and that the vegetational composition variance within each zone would explain this difference. Furthermore, Site 1 would have the highest diversity and density of crabs because it grows along an estuary where the Ushongo River meets the Indian Ocean. Therefore, it would show a mix of beach crab species and mangrove crab species, leading to higher diversity and abundance. The comparison of the mangrove forest habitat to the beach site habitat would illuminate the high diversity mangroves support and thus, the value of mangrove forests in conservation. The null hypothesis was that there would be no significant variance in the diversity, density, or distribution of crabs among mangrove forest zones. An alternative hypothesis was that there would be significant difference, however other factors would explain it in addition to vegetational variance, such as human impact.

There were several objectives for this study. The main aim was to understand the distributional gradient of mangrove trees and the relationship between crabs which inhabit mangrove forests and mangrove tree composition. Another objective was to develop a baseline survey of the existence and distribution of mangrove tree and crab species in the Ushongo area. This survey can be expanded upon in future years to develop an inventory of the flora and fauna in Ushongo mangrove forests, which could, in turn, be used for future conservation efforts. A final objective was to observe additional influences on mangrove forests in Ushongo such as human impacts.

Site Description

This study focused on the mangrove forest in Ushongo, Tanzania. Ushongo is a quaint and remote coastal fishing village and local vacation getaway located on the Indian Ocean, 16km south of Pangani, and 50km south of the large coastal city Tanga. Ushongo is composed of two villages, Ushongo Mtoni and Ushongo Mabaoni. The population of Ushongo Mtoni is approximately 435 people and Ushongo Mabaoni is approximately 300 people (Raim, personal dialogue, 2017). Most people earn their livelihoods from fishing and increasingly from tourism (Palmisano, 4). Tourism has been growing in the area, which will be a factor to consider in the human impact on my study site. This site was chosen because Ushongo offers a relatively undisturbed mangrove stand. Mangroves and crabs are abundant in the Ushongo area, and relatively undisturbed, making the area suitable for conducting this study.

The mangrove forest in Ushongo grows along the Ushongo River or within the river watershed and salt marshes created by tidal flooding. Three separate sites of mangroves were studied using the line transect method, as well as one site on the beach, in the Ushongo area from November 5th, 2017 through November 24th, 2017 (Image1). Sites were chosen based on the recommendation of my guide, Raim. He recommended the three-mangrove forest sites that chosen for this study. These three sites were distinctly characteristic.

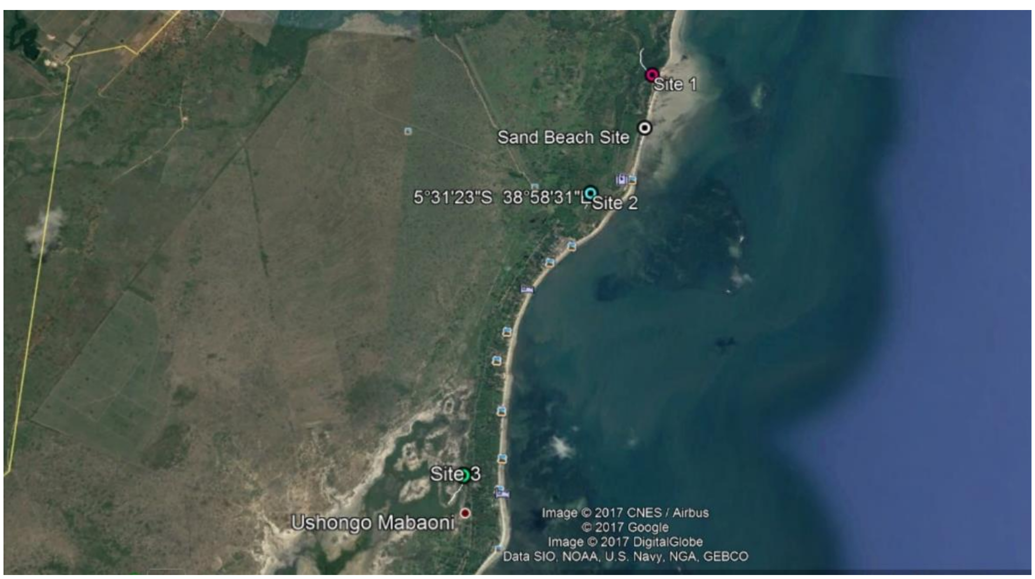


Image 1. Map of Site 1, Site 2, Site 3, and Sand Beach Site. Ushongo Mtoni is located near Site 2, while Ushongo Mabaoni is located just South of Site 3 (image courtesy of Google Earth).

Site 1 was in the estuary of the Ushongo River. The 200m line transect ran 324° Northwest from 5°30'41"S, 38°58'49"E to 5°30'60"S, 38°58'47"E. Estuaries are areas where freshwater rivers or streams meet seawater in partially-enclosed areas and are highly-productive ecosystems (Castro & Huber, 2005). The transect began at the first mangrove tree of the stand, an *A. marina tree,* which grew near the beach, and ran upstream. The river was parallel to the transect in Site 1, which was filled with numerous fish and invertebrates such as prawns and barnacles. The water level changed with the tide several times a day. In the morning, the river was high, and the tide was headed out. In the afternoons, the river was low, and the tide headed in. Four species of tree grew in the Site 1: *A. marina, C. tagal, B. gymnorrhiza,* and *R. mucronata.* Site 1 was the only site where *C. tagal, B. gymnorrhiza,* and *R. mucronata* grew. The beginning of the plot was a sandy open clearing, mainly composed of *A. marina,* and transitioned into more dense vegetation with mud/silt soil, composed predominantly of *C. tagal* trees. There was a large amount of trash and washed up seaweed covering areas of the site.

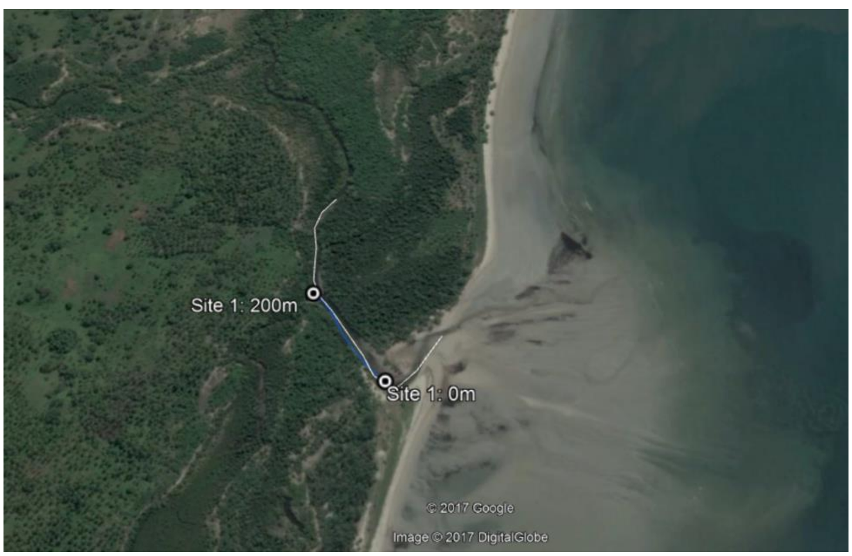


Image 2. Map of Site 1, located on the Ushongo River estuary. The transect ran Northwest from 0m to 200m.

Site 2 was a stand of mangroves near Ushonogo Mtoni village. The transect ran 211° Southwest from 5°31'23"S, 38°58'31"E to 5°31'27"S, 38°58'29"E. The forest grew behind the remains of the first tourism lodge built in Ushongo, which is no longer in operation, and by a gravel road leading to Emanyani Lodge located further down the beach. The forest was homogenous, composed exclusively of *A. marina* trees with a high density of pencil pneumatophores, mud/silt soil, and a high crab burrow density. A stream ran parallel to the transect that rose and lowered in height and width during the study period, seemingly in response to rainfall, leaving only small pools at the lowest level. Village residents come to fish in the pools occasionally and coconuts were harvested many times from trees during near the transect during data collection (Raim, personal correspondence, 2017).

Image 3. Map of Site 2, located near Ushongo Mtoni village. The transect ran Southwest from 0m to 200m.

Site 3 was further from the village near the Ushongo Primary School. The transect ran 189° South from 5°32'50"S, 38°57'59"E to 5°32'57"S, 38°57'55"E. Site 3 could be classified as a salt marsh with many shallow pools which accumulated along the muddy ground. These existence and depth of these pools was most strongly affected by rainfall, though the area likely experiences occasional tidal flooding. The only mangrove species in the Site 3 area was *Avicenna marina*. Non-mangrove plants grew in Site 3 like grass and pickle weed, which is a ground-cover succulent that grows in salt marches (Castro & Huber, 2005). People herded livestock through the area regularly, and a Maasai village was located near the site. Surrounding vegetation was predominantly shrubs and a there were large portions of exposed dirt. The area surrounding Site 3 was sparse wetland, often filled with wetland bird species such as flamingos and storks. Large swaths of this area near Site 3 had hundreds of gray stumps sitting in marsh water. These stumps appeared to be mangrove trees that had been cut down by people, likely for boat building or fencing material.

Image 4. Map of Site 3, located further from village near primary school. Transect ran South from 0m to 200m (courtesy of Google Earth).

Sand Beach site was on a stretch along the ocean between Emayani Lodge and the Ushongo River estuary (the location of Site 1). The transect ran 192° South from 5°30'60"S, 38°58'47"E to 5°31'6.33"S, 38°58'45.02"E. The location of the beach site was chosen based upon proximity to the other study sites and as an area of less human disturbance (walking) than the remainder of the beach in front of the lodges and village. A dead tree on the beach was chosen as the start of the line transect and the line extended straight down the beach. A lot of trash, mainly water bottles, were washed up on the beach.

Image 5. Map of Sand Beach Site, located between Emayani Lodge and Ushongo River estuary. Transect runs South from 0m to 200m (courtesy of Google Earth).

Method

Line Transect Method & Data Collection:

Three mangrove forest sites and one sand beach site were studied from November 5th to November 23rd, 2017 in Ushongo, Tanzania using a line transect & plot method. At each of the four study sites, a 200-meter line transect was measured from the starting point with a 30-meter tape and marked every 5 meters with rope and a distance label tied on the nearest tree branch. The aim was to keep the line as straight as possible, but this often proved difficult due to thick vegetation or pools of water which could not be navigated through. In this case, the line would have to move while attempting to maintain a straight semblance. The line transect was used to map the placement of plots, which were 2 square-meters demarcated by a square measured and drawn in the sand. In each mangrove forest site, 40 plots were observed, one being located every 5 meters beginning from 0m to 200m. Only 20 plots were recorded in the beach site, one plot every 10 meters, to be used in a habitat diversity comparison.

In each of the mangrove forest sites, a reconnaissance survey was conducted on the first day. The purpose of the survey was to record vegetation composition, mark the line transect, and note any pertinent information regarding the site that may influence the method or results. The four subsequent days were used for data collection. Each of the four days, 10 plots were observed: 5 plots in the morning (7am-10am) and 5 plots in the late afternoon (2pm-5pm). These times were chosen to ensure a range of data collection in case of difference between morning and afternoon, and because they were convenient times for my guide, Raim.

Prior to the commencement of plot observation, the $2m^2$ plot was measured and drawn in the sand and tree measurements were recorded. The observation period for each plot was a cumulative 20 minutes: 5 minutes sitting silently recording metadata to allow for the habitat to recover from the disturbance of walking around the plot, and 15 minutes recording the species and number of crabs observed within the plot. Metadata included distance from the nearest water source (if visible), soil type, type of pneumatophore and percent coverage, number of burrows in the plot, canopy coverage, type of trees in the area, weather, smells (usually sulfurous) and any disturbances during data collection, such as people or animals walking past the plot.

The method was altered slightly in the Sand Beach Site. During the reconnaissance survey, it was observed that the beach was approximately 20 meters wide in the morning with three sections demarcated by lines of dead seagrass washed ashore from previous tides. To ensure accurate measurements of crab density and diversity on the beach every morning, each plot alternated between the upper, middle, and lower zone of the beach, upper being near where vegetation began past the reach of waves, and lower being the area closest to the water. Two days were spent recording data at the beach site, 10 plots each morning beginning around 7:45am.

During data collection in all the sites, the species and number of individuals were recorded. Species were identified by writing detailed descriptions of the size and colors of individuals while in the field, and comparing these descriptions to individuals from other plots. As a rule of thumb, this classification process erred on the side of avoiding adding new species when there was significant doubt as to whether an individual was a new species or an old species. These classifications were then compared to the descriptions and images of mangrove crabs from sources such as "A Field Guide to the Seashores of Eastern Africa and the Western Indian Ocean Islands." (Richmond, 2011) to create a catalogue and identify as many species as possible (Appendix II).

Care was taken throughout the data collection process to have as little negative impact on the ecosystem as possible. To minimize disturbance to the crabs, damage to crab burrows and vegetation was avoided as much as possible. Although a guide was likely not very needed as this study project was solitary by necessity and design, it seemed most appropriate as a visitor to another village to respect the people who lived there and their ownership over the land by having a guide to explain and facilitate the study. Additionally, as we lived in the village for almost a month, we made sure to give back to the village whenever possible by shopping at local stores and eating at hotellinis, rather than other spending money at lodges.

Analysis of Data:

Preliminary data analyses established measures of species richness and abundance of each site. Site specific data analyses included finding average tree, canopy, pneumatophore, and crab burrow measurements and analyzing the distribution of mangrove tree species and the density of crab species along the line transect. Simpson's Index of Diversity, ANOVA, and paired t-tests were used to compare data between sites. ANOVA single-factor analysis was used to test for significant variance in the number of individuals per plot between each mangrove forest site and significant variance in the number of species found per plot between each mangrove site. Paired t-tests between each combination of two sites illuminated from where this significant variance stemmed.

Species richness, abundance, Simpson's Index of Diversity, and environmental composition were used to compare the mangrove habitat to the sand beach habitat. When conducting this comparison, only the data from 20 plots in each mangrove site was used (every 10m plot) because only 20 plots were measured across the 200m line transect at the Sand Beach site. This was done to minimize skewed data and bias.

Results

Site Specific Results:

Each site had different distributional patterns. These patterns are illustrated using diagrams which show the mangrove tree species, mud type, and crab species found throughout the 200-meter line transect. Dividing the crab data results total transect into 10-plot sections (50m sections) further illustrates the micro-zones within each site.

In Site 1, a total of 493 individuals and 15 species were recorded in 40 plots (see table 1). The most abundant species recorded was *Uca annulipes* with 142 total individuals. *Ocypode pallidula* was the second most abundant species with 86 total individuals, and *Ocypode ortmanni* was the third most abundant species with a total of 63 individuals.

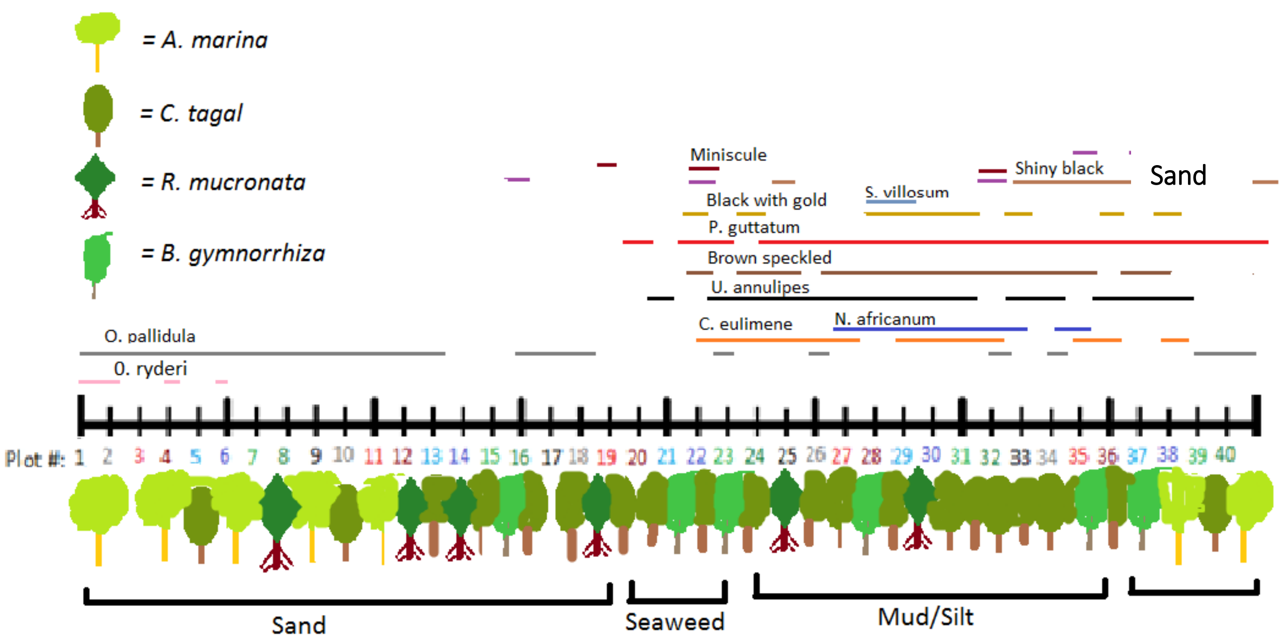
Species	#	Species	#
U. annulipes	142	*Hermit crab*	11
O. pallidula	86	*O. ryderi*	8
C. Ortmanni	63	*Miniscule*	4
Brown speckled	49	*S. villosum*	4
P. guttatum	38	*C. carnifex*	1
Black with gold	36	*Green/gray*	1
N. africanum	31	*Red, black & white legs*	1
Shiny black	18		

Table 1. List of all species found in Site 1 and the total number of individuals counted in each species ordered from most abundant to least abundant.

Site 1 had a variety of vegetational compositions, mud types, and crab species distributed throughout the 200-meter transect. Four species of mangrove tree grew throughout the 200m line transect in Site 1. The growth pattern of these trees exhibited micro-zones within Site 1. There was an average of 0.78 trees per plot across Site 1 with an average tree height of 3.93 meters and average circumference of 28.25cm. Diagram 1, included below, illustrates the distribution of vegetation and crab species seen throughout Site 1.

Within Site 1, *A. marina* was predominant from 0m to 50m, with a handful of *C. tagal* and *R. mucronata* interspersed. This 50-meter area was an open clearing with sparse vegetation and sand sediment. The average number of species per plot from 0m to 45m was 1.7, and had a total of 70 crabs. From 50m to 95m, C. tagal was predominant within *B. gymnorrhiza* and *R. mucronata* interspersed. This spread of the transect had a mix of sand and mud/silt soil. The 50 to 95m area had 17 crabs recorded and an average of 0.8 crabs per plot. C. tagal was again the most predominant from 100m to 145m interspersed with *B. gymnorrhiza* and *R. mucronata*, and the soil was a mixture of mud and silt. A total of 218 crabs were recorded in this area with an average of 5.2 species per plot. From 150m to 200m, all four species of mangrove grew, and the soil type changed from silt to sand. There was an average of 4.6 species per plot and a total of 187 crab individuals recorded from 150m to 200m.

Diagram 1. Illustration of the distribution in Site 1 of the 4 mangrove tree species, soil type, and crab species



throughout the 200-meter line transect. Colored lines represent occurrence of each species and plot numbers are labeled below line transect.

Site 2 was composed exclusively of *A. marina* mangrove trees and a mixture of mud and silt soil. Four species of crab were recorded within Site 2, two of which being dominant (Table 2). A total of 706 crab individuals were recorded. Of these, 356 were *C. ortmanni* and 344 were *N. africanum*. Additionally, two *U. annulipes,* and four *miniscule brown crabs* were recorded.

Species	#
C. ortmanni	356
N. africanum	344
Miniscule brown	4
U. annulipes	2

Table 2. List of all species found in Site 2 and the total number of individuals counted in each species ordered from most abundant to least abundant.

An average of 2.3 species per plot and a total of 152 crab individuals were recorded from 0m to 45m. Both the 50m to 95m section and the 100m to 145m section had an average of 2 species per plot and a total of 173 individuals recorded. 208 individuals were counted from 150m to 200m. with an average of 2.1 species per plot. *C. ortmanni* and *N. africanum* were recorded evenly throughout the 200m transect.

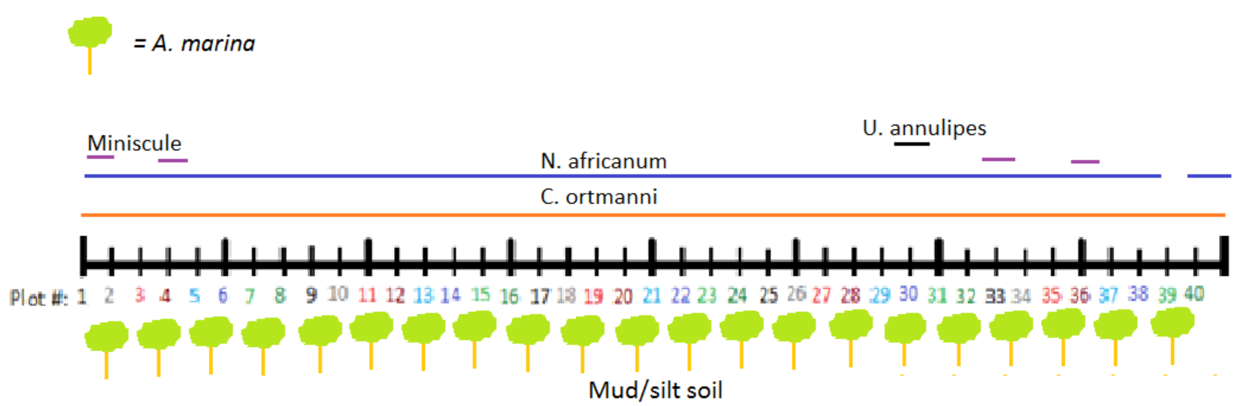


Diagram 2. Illustration of the even distribution in Site 2 of *A. marina*, the mud/silt soil type, and crab species throughout the 200-meter line transect. Colored lines represent occurrence of each species and plot numbers are labeled below line transect.

In Site 3, 534 individual crabs belonging to 4 separate species were counted (Table 2). *C. ortmanni* was the most abundant species in Site 3 with a total of 491 individuals recorded. There were 37 *N. africanum* individuals, 5 *miniscule brown crabs*, and 1 hermit crab counted.

Species	#
C. eulimene	491
N. africanum	37
Miniscule	5
Hermit crab	1

Table 3. List of all species found in Site 3 and the total number of individuals counted in each species ordered from most abundant to least abundant.

Diagram 3, included below, illustrates the distribution of vegetation, soil type, and crab species throughout Site 3. Site 3 was comprised exclusively of *A. marina* mangrove trees. The average number of trees per plot in Site 3 was 1.7, with an average height of 3.37 meters and an average circumference of 16.68cm. *C. ortmanni* and *N. africanum* crabs were both distributed evenly throughout the site. From 0m to 45m, there were a total of 203 individuals recorded and an average of 1.9 species per plot. The soil type in this area was gooey mud with cow manure, as it was located next to the cow trail. The section from 50m to 95m also had gooey mud. A total of 93 individuals were counted in this section, and an average of 1.5 species per plot. There was an average of 1.1 species per plot from 100m to 145m, and a total of 77 crab individuals. Most of the soil in this section was sandy sediment. This section also had grass and pickle weed succulent ground cover growing in the plots (Appendix III). The last section, from 150m to 200m, had hard dry mud, an average of 1.7 species per plot, and a total of 161 crab individuals.

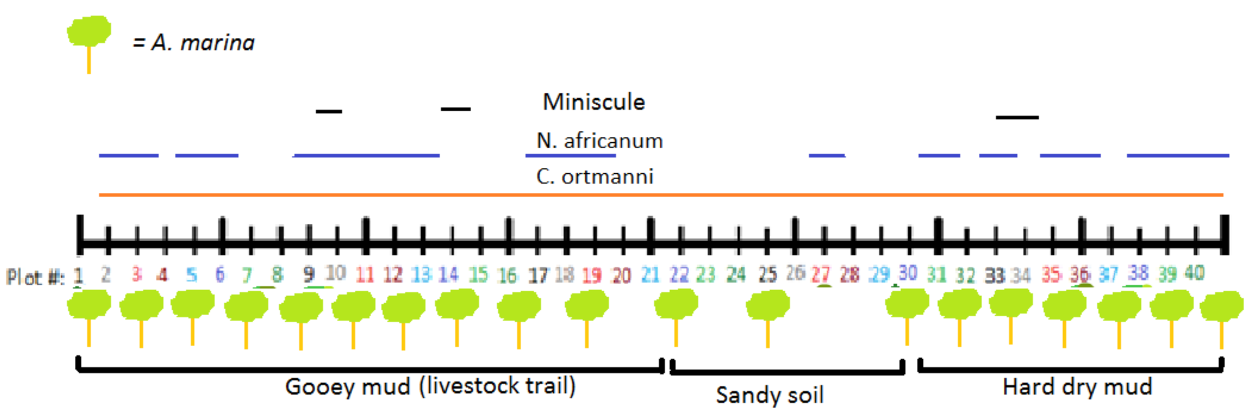


Diagram 3. Illustration of the even distribution in Site 3 of *A. marina*, three soil types, and crab species throughout the 200-meter line transect (hermit crab not included due to only 1 occurrence). Colored lines represent occurrence of each species and plot numbers are labeled below line transect.

In the Sand Beach Site, 33 total individual crabs were recorded which belonged to two species: *O. ryderi* and *O. pallidula. O. ryderi* was observed in the highest abundance, with a total of 29 individuals recorded, while there were 4 *O. pallidula* individuals. The density was 0.412 individuals per m^2 and an average of 1.18 species per plot.

Abundance and Species Richness Comparison:

A total of 1,766 individual crabs and 15 crab species were recorded over the duration of the study period, including those from the Sand Beach Site. Within just the mangrove sites, a total of 1,733 individual crabs were recorded. 41% of these individuals were found in Site 2, 31% in Site 3, and 28% in Site 1, thus Site 2 had the highest abundance (Figure 1). When factoring in the Sand Beach, species richness and abundance was compared across only 20-plots, located every 10m to match the 20 plots measured in the Sand Beach Site. The Sand Beach Site had only 4% of the total crab abundance, when considering all four sites (Figure 2). Site 1 had the highest species richness of 15, followed by Site 2 and 3 which both had a species richness of 4, and the Sand Beach with a species abundance of 2 (Figure 3).

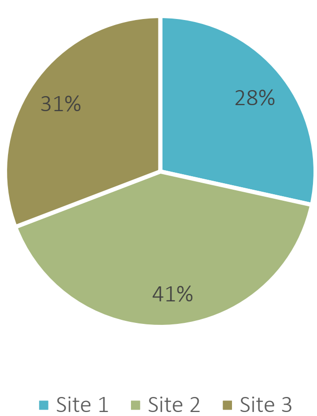


Figure 1. Percentage of total crab abundance found in each of the three mangrove forest sites.

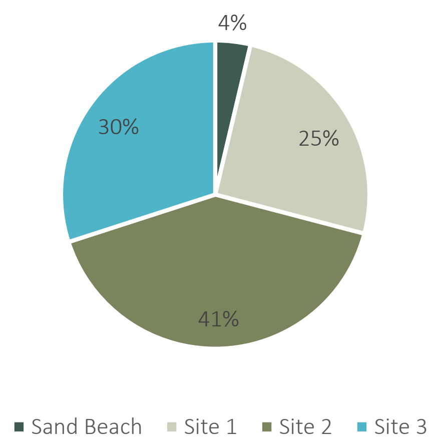


Figure 2. Percentage of total crab abundance found in each of all four study sites.

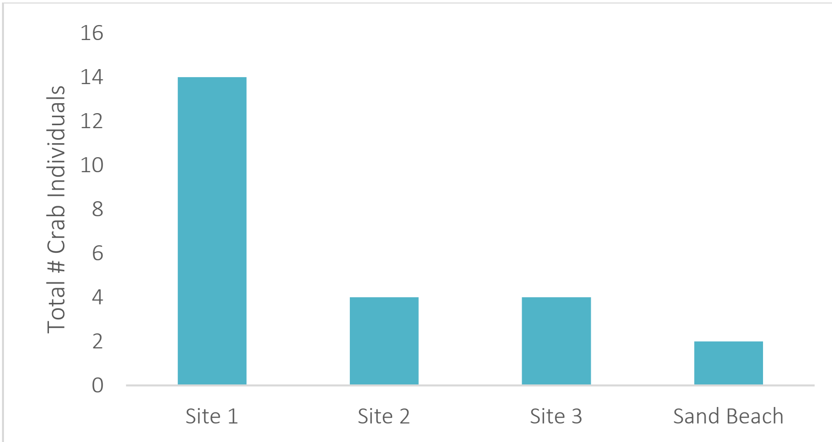


Figure 3. Species richness among the Sand Beach Site, Site1, Site 2, and Site 3.

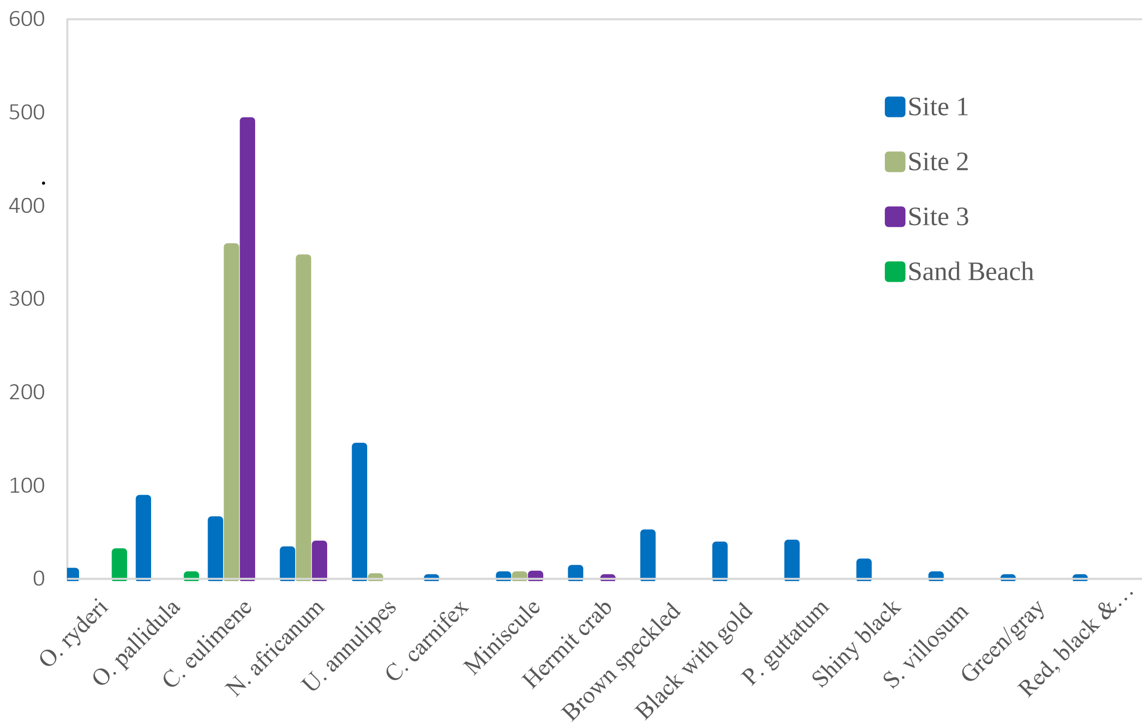


Figure 4. The abundance of each species in number of individuals in each of the four sites.

Diversity

The Simpson's Index of Diversity was used to compare the diversity of each site. Index values close to 1 indicate high levels of diversity and evenness while values closer to 0 indicate low diversity. The values in parentheses indicate the index values resulting from 20-plot analyses within each mangrove site, if the values were different from that of the 40-plot analyses. This allows more accurate comparison to the Sand Beach Site. Site 1 had a diversity index of 0.84, which indicates a high diversity value. Site 2 has a diversity value of 0.51. Site 3 has a diversity value of 0.15 (0.14) and the Sand Beach Site has a diversity value of 0.22, both of which indicate low diversity and evenness (Table 4).

	Species Richness	**Total Individuals**	**Simpson's Diversity Index**
Site 1	15 (14)	493 (227)	0.84 (0.86)
Site 2	4	706 (366)	0.51
Site 3	4	534 (268)	0.15 (0.14)
Sand Beach	2	33	0.22

Table 4. Table of Species Richness, total individual crabs recorded in each site, and the calculated Simpson's Index of Diversity for each site. Values in parentheses indicate the Simpson's Diversity Index for 20-plot analysis, if different from that of the 40-plot analysis.

Density

Preliminary density data analyses took the total abundance divided by the total area of all plots (Table 4). The density of Site 1 was 3.08 individuals per m^2 across 40 plots ($160m^2$), and 2.84 individuals across the 20 plots. In Site 2, there were 4.41 individuals per m^2 across 40 plots, and 4.58 individuals across 20 plots. Site 3 had 3.34 individuals per m^2 across 40 plots and 3.35 individuals per m^2 across 20 plots. The sand beach had 0.41 individuals per m^2 across the 20 plots.

Site	**Density (Individuals per m^2)**
Site 1	3.08 (2.84)
Site 2	4.41 (4.58)
Site 3	3.34 (3.35)
Sand Beach	(0.41)

Table 5. Table of the density of plots in each site. Calculated by dividing total number of individuals each site by the total area ($160m^2$). Values in parentheses indicate density calculated from 20-plot analysis ($80m^2$ area).

A single-factor ANOVA test was run on the number of individuals per plot found in each of the three mangrove sites. The resulting p-value from the test was 0.049, less than the significance value of $p = 0.05$, so there was significant variance in density between the three mangrove sites. Paired t-tests were run between each possible site pair to further discover from where this variance stemmed with a significant value of 0.05. The t-test between found significant difference in density between Site 1 and Site 2 with $p = 0.026$. Site 2 and Site 3 also had significant difference with $p = 0.048$. There was no significant difference in density between Site 1 and Site 3 with $p = 0.669$.

Discussion

The hypothesis prior to the commencement of this study was that there would be significant variance in the diversity, density, and distribution of crabs among three mangrove zones, which would be correlated to vegetational diversity, distribution, and composition. The results of the study supported the hypothesized significant variance in diversity, density, and distribution of crabs between the mangrove forest zones. Significant variance in density and the number of species found in each plot was found between the three mangrove sites, so the null hypothesis can be rejected. As hypothesized, Site 1 had the highest diversity index of all the sites (0.86), as well as the highest number of mangrove tree species. There was a high degree of variance in mangrove tree species distribution, soil type, and crabs throughout the line transect in Site 1. When the transect is sectioned into quarters, there are obvious micro-zonal correlations between the soil type, predominant tree, and crab species and abundance recorded.

The results of the ANOVA test showed significant variance between all three mangrove sites in the number of individuals per plot ($p=0.49$) and in the number of species per plot in each site ($p = 0.0004$). There was significant variance in the number of individuals per plot between Site 1 and Site 2 ($p=0.026$) and Site 2 and Site 3 ($p=0.048$). However, there was not significant difference in number of individuals per plot between Site 1 and Site 3 ($p=0.669$). The ANOVA test found significant variance existed between all three sites ($p=0.0004$) and subsequent paired t-tests found all three site pair combinations also had significant differences: Site 1 & Site 2 ($p=0.033$), Site 1 & Site 3 ($p=0.002$), and Site 2 & Site 3 ($p=0.003$).

It was hypothesized that Site 1 would have the highest diversity of all the sites because it was located where the river flows into the ocean, therefore most directly spanning freshwater and saltwater, terrestrial and marine habitats, leading to high diversity. The results confirmed this hypothesis. Site 1 had the highest number of species per plot (2.85), which supports the high diversity found in Site 1 based upon Simpson's Diversity Index. The highest average number of species per plot in Site 1 were found from 100m to 200m where all four species of mangrove tree grew, and the soil was mud/silt. Certain crab species prefer certain types of mangrove trees, so more mangrove tree species allows for more crab species. A previous ISP studying the zonation of *S. alba* in Kigombe, found zonation in the seedling density which was correlated to crab burrow density variance, and the highest density of seedlings was found on the seaward side on the stand (Lawlor, 2013). This study also suggests a correlation between crab and mangrove flora distribution, with the highest diversity being found in the area closest to the ocean.

Site 1 was hypothesized to have had the highest density and abundance of crab species, but this was not proved with the results. Site 2 was the most homogenous and had the highest abundance and density of crabs. *C. ortmanni* and *N. africanum* occurred in nearly equal abundance evenly throughout the whole site. These two species are often correlated to each other and are primarily found dominating *A. marina* zones. The data suggests that the homogeneity of Site 2 has influenced these two species to become specialized to this area. The leaves of *A. marina* have a high nitrogen and low tannin content, which makes them very favorable for herbivores such as *C. ortmanni* and *N. africanum* (Micheli, et al., 1991). Site 3 had the lowest diversity index (0.15), homogenous vegetation, and the most human/livestock impact observed.

Overall, this study shows there is a high level of diversity within these mangrove forests sites not only in crab species, but in distribution and densities too. Some zones are heterogenous and support high species richness and generalization, while others are homogenous and support specialization. This diversity in habitat dynamics shows how adaptable to and influenced mangrove forests are by environmental conditions. The data suggests an obvious difference in crab composition and distribution, as well as vegetational zonation, and other factors such as human impact. While there is insufficient data to draw concrete conclusions as to which of these factors, and to what degree, influenced the crab diversity and densities, it suggests a strong correlation.

Comparing the 3 mangrove sites to the Sand Beach Site shows the difference in crab composition between habitats and the abundant diversity which exists in the Ushongo area mangrove forests. A previous ISP study from 2012 studied crab species among four habitats in Ushongo. The study found 8 crab species within 4 plots in the mangrove habitat, two of which were also recorded in this study, and it found no community similarity between mangroves and other habitats such as the sand shore (Palmisano, 2012). This study supports the finding of a large difference in habitat between mangrove and sand beach, and shows the importance of conserving mangrove habitats because of the unique diversity it supports which is unlike other that of other habitats.

Human impact was observed in all the sites to varying degrees. Site 1 had the lowest human impact observed, most of which only involved people walking or driving motorcycles on the nearby beach. In one instance, a man entered the mangrove forest and cut down a mangrove tree. This is an illegal act in Tanzania, unless you have obtained a permit. There was a great deal of trash in Site 1 which was washed up with piles of seaweed from high tide. Site 2 was located near Ushongo Mtoni and the walking path that ran parallel to the line transect had a lot of foot traffic, including goat herds passing by. On several occasions, people came and cut down mangrove tree branches. Site 3 seemed to have the highest level of human disturbance. Because it was located near the school, kids walked through or hung out in the forest several times a day. There was also the Maasai village nearby, and cows, goats, or sheep would pass through the site. Another ISP study from 2012 assessed the macrofaunal diversity of the mangroves in Ushongo in relation to water depth, time of day, and human impact, but found no correlation to any of these variables (Perry, 2012). It seems inconclusive whether the human impact influenced the observed crab variance and this previous study was insufficient, or whether vegetational composition has a far larger impact than human disturbance does.

Looking back to the study by Giblock & Crane (2013), data about mangrove crabs such as this can be used to indicate the environmental health within a mangrove forest. Understanding why Site 1 had a higher diversity of crabs but Site 2 had a significantly higher abundance of crabs while Site 3 had the lowest diversity and least evenness may indicate the health of these ecosystems and whether this health needs to be improved.

Limitations and Biases

Several limitations and biases likely affected this study. Most of these biases are methodological consequences which are somewhat unavoidable, but can be mitigated. The large number of plots measured and resulting data from each site compensates for most of the following biases. In addition, the results were consistently significant, so it is unlikely that and error such as overestimation of species richness or abundance would affect the overall conclusions of this study.

Subjective species identification was the most significant bias in this study. A component of this subjective identification is a consequence of the plot observation method because crabs are observed from a distance which makes it difficult to distinguish between species. For example, C. ortmanni and C. eulimene look nearly identical until looked at with a trained eye through a magnify glass and using a ruler. Based upon information about the habitat and behavior of each species, it was assumed that C. ortmanni was in the plots, however it is likely both inhabited the mangrove forests when only C. ortmanni was recorded. Furthermore, there is limited knowledge about mangrove crab species in Tanzania, both within my own knowledge and the information available in literature.

The line transect method has limitations as well. The plots were non-randomized and only located along one line running parallel to the river or water source. This leaves out areas of the forest outside of the plot, such as landward to seaward gradients, so the study results cannot be generalized to the site areas. There were additional biases resulting from the plot-observation method. The presence of my guide and me likely impacted the data because crabs are very skittish and responsive to any movement, which is often inevitable especially when there were many mosquitos. I attempted to remain as still as possible, and my guide, Raim, usually sat far away from the plot during observation to minimize bias. Many people and animals passed by the plots during observation periods and would disrupt the crabs. This included a stray dog which followed me all the way to the plots one afternoon and insisted on staying. Several plots were covered with dense vegetation or seaweed and trash, which made it difficult to adequately see each crab individual. Crab are also most active at dawn and dusk, but this study was conducted during the day due to practicality, so many crabs were likely missed, meaning it is likely the species richness and abundance results are underestimations. For example, Palmisano found 6 different crab species within 4 plots in the mangroves, which suggests either misidentification, a small sample size, or the impact of measuring at different times of day (Palmisano, 2012).

Additionally, each site was measured in cohesive blocks of time, so they were measured at different times of the month. This difference could lead to bias due to differences in factors such as weather and tidal patterns. There was no reliable equipment available to measure air temperature or salinity. In the future, these would be interesting to consider in light of observed differences in crab species distribution and composition.

Conclusion

The aim of this study was to assess the composition and distribution of mangrove crabs between three mangrove forest zones in Ushongo, Tanzania by measuring diversity and density. It was hypothesized that there would be significant differences in the diversity and density of these three zones which could be explained by the composition of mangrove tree species within each zone. Significant differences were found in diversity, distribution, and density of mangrove crabs between the 3 sites, so the null hypothesis was rejected. However, although the mangrove tree zonation led to different diversity indices and densities, there is insufficient data as to whether this is entirely due to differences in vegetational composition or a combination of several other factors such as human impact. This study highlights the valuable biodiversity found in mangrove ecosystems, especially when comparing the mangrove ecosystem at large to the Sand Beach Site. The diversity and abundance of crab species in all the mangrove sites as opposed to the beach site illuminates why mangrove forests are critical habitat that should be conserved. Human disturbances were observed multiple times over the course of the study. Although mangroves in Tanzania have been protected and maintained successfully since the National Mangrove Protection Plane in 1994, it is evident that continued protection and conservation of mangrove forests in the Ushongo area and Tanzania at large is crucial.

The implications of this study are small-scale and rather insignificant in the grand scheme of global mangrove research. Yet, such studies are necessary to build greater knowledge about East African mangroves. This study provides critical baseline information for future studies, which would ideally be made available to the village government to be used in monitoring and conservation of the Ushongo mangrove forest.

Future studies could look at many components to elaborate on this study. A study surveying and mapping the whole mangrove forest area in Ushongo would be very interesting and important work to have a baseline of the forest to be used in the future to see how the forest has or has not changed in response to different factors. Continued crab studies, or diversity and density studies of other organisms such as birds or invertebrates like barnacles or snails, or terrestrial animals such as lizards would be important to continue developing an inventory of the Ushongo area mangrove forest. For future crab studies, it would be interesting to study differences in distribution of crab species in plots running perpendicular to the water as opposed to parallel to see whether there is a gradient horizontally in addition to vertically. Simply repeating this study using measures of salinity, temperature, and quantifying human impact is another possible future study. Within social science, a project looking at the conservation of mangroves in Ushongo and what is or isn’t working could also be interesting.

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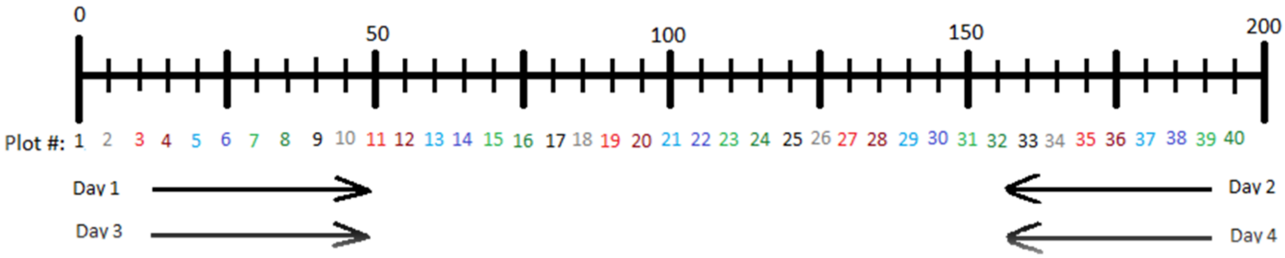
Appendices

Appendix I.

Line Transect & Plot Map



Appendix II.

Crab Species Catalogue

#	Identification	Family	Description	Size
910	*Chiromantes ortmanni*	Sesarmidae	Black body with beige/gold speckle pattern on top (almost leopard print looking), orange translucent claws with white at the tips	5-20mm
412	*Neosarmatium africanum*	Sesarmidae	Blue/black body, brown legs, Orange/red claw white at tip. Associated with C. ortmanni.	40mm
144	*Uca lactea annulipes*	Ocypodidae	White & Black spotted, one huge light pink/white claw. Sometimes body is black with white spots, sometimes body is white with black spots. Very long ovular body. Thin protruding eyeballs coming out top of head.	3-7mm
90	*Ocypode pallidula*	Ocypodidae	White body (almost translucent quality) speckled with gray and black. Thin legs with black stripes. Blend in very well to sand. Light bulb-shaped green/yellow eyes protruding from middle/top of head.	3-5mm
49	Unknown	Sesarmidae	Brown body with black or white speckled pattern, thin and square body. Eyes on front corners of body.	5-10mm
38	*Perisesarma guttatum*	Sesarmidae	Brown/black body, bright red claws	5mm
37	*Ocypode ryderi*	Ocypodidae	Pink body, purple joints (extremely common on beach).	15-30mm
36	Unknown		Round thick black body with gold/yellow spotted leopard-like pattern. Yellow/golden	7mm-15mm

			tinge to claws.	
18	Unknown		Shiny brown/black crab, thick body	4-10mm
13	Unknown		Miniscule brown speckled crab (could be juvenile of another species)	3mm
12	*Hermit crab*	Suborder: Anomura	Hermit crab	Range
4	*Sesarma villosum*	Sesarmidae	Deep brick red/brown rough looking armored shell, square body	10mm
1	*Cardisoma carnifex*	Gecarcinidae	Carnifex crab	60mm
1	Unknown		Green/gray tortoise body, yellow/green eyes	10mm
1	Unknown		Red/orange back, black, and white striped legs	4mm

Appendix III.

Image of ground cover vegetation found from 100m to 140m in Site 3. Likely belongs to the pickle weed succulent family, which is a prominent type of vegetation in salt marsh habitats.